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SAND AND CLAY:

Their Analysis and Physical Properties.

BY

AUGUSTINE C. PASSMORE.

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Their Analysis and Physical Properties.

BY

AUGUSTINE C. PASSMORE

(*Author of "Technical Terms used in Architecture and Building."*)

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PREFACE.

THE object of the following work is to present within a small compass a popular and practical statement of the Analysis and Physical Properties of Sand and Clay in their relation to building work. Few subjects have a wider interest, as sand and clay may be said to be the basis of most all our building materials.

AUGUSTINE C. PASSMORE.

January, 1907.

SAND AND CLAY.

CHAPTER I.

SAND AND ITS ANALYSIS.

THE term "sand" is applied to any mineral or siliceous substance in a fine state of division, or in a hard granular form, such as the schistose, granitic, and calcareous rocks, freestone, etc., which have been reduced to a granular state by spontaneous disaggregation or by the agitation of water. The sand employed for building purposes usually consists chiefly of silica (Si O), but it may be either quartz sand or flint sand, and is frequently a mixture of both. Sand is insoluble in water and has grains of an appreciable size. It is distinguished from powder by at once falling to the bottom when thrown into water without discolouring it or altering its transparency to any considerable extent.

Sand is found strewn upon the surface of the earth, in strata at certain depths, or forming the beds of rivers or shores of the sea. It may be divided into two classes "siliceous" and "calcareous"; but is more particularly denominated according to the nature of the predominant constituent. It is found in many grades of purity; when it consists almost entirely of silica it is termed "siliceous" sand, when it contains much silicate of alumina (clay) it is called "argillaceous" sand, and when it contains much carbonate of lime it is known as "calcareous" sand. The siliceous sands are pit sand, river sand, and sea sand. By examining the particles composing sand, the source from which they are derived can easily be ascertained. Flint and quartz are almost identical in chemical composition, both consisting almost entirely of silica, but both generally contain small quantities of iron and other impurities. Of the two forms of sand the quartz is usually the purer.

The schistose rocks produce a sand with lobular shaped grains which are very tender and soon reduced to a powder when washed by rains and currents of water. The granite rocks produce a sand composed of grains of felspar, mica, and quartz; whilst volcanic rocks furnish lavas of all kinds. The fossil sands are found deposited in situations where now neither brooks nor rivers flow; they generally have a more angular grain than sea or river sand, but consist mainly of the same constituents. A sand belonging to the fossil order is the arene sand; it is generally quartzose and composed of very irregular and unequal grains; it is found united with clay in proportions varying from one to three fourths.

It has been pointed out by Sorby and others that, by the aid of the microscope, much may be learned concerning the history and character of sand grains. He (Sorby) has classified them into five groups, which, however, graduate into each other. These are (1) Normal, angular, fresh-formed sand, such as has been derived almost directly from the breaking up of granite or schistose rocks. (2) Well-worn sand in rounded grains, the original angles being completely lost, and the surface looking like fine ground glass. (3) Sand mechanically broken into sharp angular chips, showing a glassy fracture. (4) Sand having the grains chemically corroded, so as to produce a peculiar texture of the surface, differing from that of worn grains or crystals. (5) Sand in which the grains have a perfectly crystalline outline, in some cases undoubtedly due to the disposition of quartz upon rounded or angular nuclei of ordinary non-crystalline. In the manufacture of bricks fired at a low temperature, number 3 above described is, no doubt, the best, as it possesses certain binding properties ; but the usual type of sand met with in ordinary circumstances is either number 1 or number 2.

The calcareous sands are the least common and are produced from oolitic stones or rocks. They are usually friable—that is, comprised of soft particles, in which case they are less suitable for mortar making. The oolitic stones or rocks are not susceptible to what may be called granitic disaggregations, as if they belong to the hard variety they produce scaly splinters or laminar grains, whilst if they be of the soft variety they produce powder. Although calcareous sand is ordinarily inferior to silica sand, nevertheless it is certainly true that the use of calcareous sands yields a much stronger concrete or mortar, in both tension and compression, than natural sand, and the difference of strength seems to increase with the age of the concrete or mortar ; this is chiefly on account of the porous nature of calcareous sands, but they are not so good as siliceous sands if absolute water tightness is desirable. Part of the greater strength is unquestionably due to the greater sharpness of the screenings, and the part that increases with the age of the mortar seems to be due to some chemical action between the cement and the limestone.

The purity of sand is often affected during the natural process of its being deposited in the beds of rivers by flowing over beds of clay or mould or uniting with vegetable debris and animal matter. The quality of the sand has an important effect upon the strength and durability of the mortar or concrete, although its importance is generally overlooked, even when the cement is subject to the most rigid specification. It is generally believed that the chemical nature of sand has not any important bearing upon its value for mortar, but it has been shown by E. Donath and others that the sand used for mortars is rarely pure quartz, but almost invariably contains silica in a form which, unlike quartz, is capable of entering into chemical combination with lime. This active silica varies in proportion in different sands. Pure quartz sand is practically inert when in contact with lime, but modern research indicates that flint slowly enters into chemical combination with lime to form calcium silicate, whereas quartz sand is almost insoluble in hot dilute caustic soda solution under normal pressure, whereas flint is readily dissolved by this solution. Silica in the form of quartz crystals differs, therefore, in certain properties from silica in the form of flint.

The physical condition of sand is a matter of primary importance; it should be clean, free from fermentable matter, and should have sharp edges. An admixture of clay—and few sands (except sea sand) are entirely free from this—is detrimental. Experiments have been made which showed that the strength of cement mortars, made with sand containing about 8 per cent of loam was, at the age of six months, about 40 per cent less than the strength of similar mortars made with perfectly clean sand. This is certainly an exceptional loss of strength, but impurities in sand undoubtedly reduce the strength of mortar very considerably. In the use of sand in mortar it is essential that the union between the sand and lime should be uniform and complete ; the presence of foreign .substances such as the admixture clay, soil, slime, or other impurities, will kill much of the lime or cement, causing the mortar to disintegrate or become rotten in a very short time after setting ; in fact, if the foreign substances are present in great excess the mortar will not set at all. The presence of foreign substances interfere with the chemical action by which, in the process of uniting mortar, a fine silicate of lime is formed round each grain of sand. To ascertain the presence of impurities, the foreign particles are nearly always of the dust nature in dry sand, and can generally be detected by rubbing sand in the hand, thus freeing the dust from the grain. This same defect may also be discovered in wet sand by moulding the sand in a cloth or the palm of the hand, the compression wringing out the moisture. The water wrung from the same will be discoloured to the extent of foreign substances contained therein, or the depth of the stain left on the hand indicating the amount of the impurity, or it may be judged for cleanness by pressing it together between the fingers while it is damp, and if the sand sticks together when the pressure is removed it is unfit for use for mortar. The cleanness of sand may also be tested quantitatively by agitating a quantity of sand with water in a graduated glass flask ; after allowing the mixture to settle, the amount of precipitate and of sand may be read from the graduation. Care should be taken that the precipate has fully settled, since it will condense for a considerable time after its upper surface is clearly marked. The cleaner the sand the stronger and the healthier the mortar, that is to say, that a mortar which has lost its strength through the use of dirty materials cannot be healthy. All sand should be condemned as unfit for mortar making without the sand be washed which is impregnated with over 8 per cent of clay or earthly impurity.

The value or usefulness of sand of the different kinds may be placed in the following orders :—(1) Pit sand. (2) River sand. (3) Sea sand. Pit sand, on account of its rough, sharp angular grains, is best, but it must be freed by washing from earthy, loamy, or clayey matter, or other foreign substances ; on this account river or freshwater sand is sometimes preferred, as it is freer from particles of clay and dirt. Pit sand is usually yellow or red owing to the presence of iron oxide. River sand is water-worn and usually has smooth and round grains, its sharpness being destroyed by the action of the water, and does not therefore afford so good a "grip" to the setting lime or cement as pit sand. It has usually the advantage of cleanliness and freedom from soluble alkaline salts, but that obtained from tidal rivers should always be washed. For plaster work river sand is often preferred on account of its freedom from colour, and being of larger grain. It should be free from mud or ooze, and as large grained as possible, a bright, sparkling, clear-running stream being more likely to furnish it than a sluggish one. River sand is largely used for rough cast work. Pit sand, as a rule, is not suitable for compo work or cement rendering, river sand being much preferable. Bar sand refers to sand taken from river beds and shoals. It is nearly always clean enough to be used in its original state, but it is sometimes filled with small grains of coal and vegetable matter, which expands from absorption after cement has set, thereby causing pit marks. The grains of coal and vegetable matter can be separated by screening the sand into a tank of water and removing all particles that float ; the grains of coal are not such an objection as the vegetable matter.

Sea sand has not only the fault of being waterworn, but is also impregnated with alkaline diliquiscent salts ; this does not appear to detract from the strength of the mortar—beyond causing it to set slower—but the salt may render the mortar damp and may cause efflorescence in brickwork. Generally, sea sand is condemned on account of its containing large quantities of saline matter, and its retaining much moisture ; in fact, it is hygrometrical, that is, in damp weather it will become moist owing to the salt in it, and will remain so until the weather changes and the atmosphere dries. A wall plastered with sea sand would be a perpetual barometer. Sea sand may be admissable in some cases after being well washed in fresh water, and exposed to the weather for, at least, six to nine months. Sea sand, or that from tidal rivers, should always be avoided for plastering as the grains are round, smooth, and contain various salts which cannot be altogether removed by washing. Sea sand should only be used for marine works executed with Portland cement. Those in charge of work situated near an estuary or the sea would keep a sharp look out on the sand brought on the job.

The selection of sand for moulding or casting in foundry works is of primary importance; certain percentages of silica, alumina, etc., must be present before it can be considered to be moulding sand, but fineness may be obtained by mechanical treatment in pan mills or other suitable means. Alumina may vary from 3·70 per cent to 5 per cent. A sand containing 6·34 per cent of alumina has been found to give trouble by "scabbing" the green sand moulds, when mixed with black sand in the usual proportions. Sand having 9 per cent of alumina may be used for dry sand moulds, but is apt to cause cracks in the mould when drying. There should not be any lime, potash, or soda present, as these increase the fusibility. Moisture should not exceed 2½ per cent at most. The colour of moulding sand is of no importance. When sand is red the colour is due to ferric oxide. In yellow sands the colour is due principally to the alumina present. The ferric oxide, however, gives a strong red colour if fully 2 per cent be present, although there may be over 6 per cent of alumina, showing the red oxide of iron to be a powerful colouring agent.

Oxide of iron when present as one of the constituents of moulding sand is said to have the power of assisting to put a skin on the casting. It should not be over 5 per cent, as every increase makes the sand more fusible. From 2 to 2¾ per cent of oxide of iron is found to be a suitable quantity for the purpose.

Generally speaking, sand should not have the whole of its particles of one size, so that when used for mortar, there is a small percentage of the finer granulations, and the volume of the interstices thoroughly filled. In cement mortar, fine sand of equal value and quality is better than coarse sand, and shows higher tensile and compressive strains. According to a comtemporary, sand weakens cement to the extent as follows :—

Sand	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3	4	5	6	7	8
Strength ...	1	$\frac{2}{3}$	$\frac{1}{2}$	40	$\frac{1}{3}$	30	$\frac{1}{2}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{8}$

Sand should be sharp or gritty, and seen through a microscope each grain should be all angles and not rounded. The absence or want of sharpness may possibly indicate the presence of impurities or minute foreign particles, an insufficient size of the grains, or some peculiarity of shape, or surface, or hardness, that prevents the lime or cement from adhering to them with sufficient compactness or tenacity. Sharp sand—that is, sand with angular grains—is preferred to that with rounded grains on the assumption (1) that the angular grains are rougher, and, therefore, the cement will adhere better ; and (2) that the angular grains offer greater resistance to moving one or the other under compression. On the other hand, the sharper the sand, the greater the proportion of the amount of cement required to produce a given strength or density. But a higher degree of sharpness is more important than a small per cent of voids. The smaller the proportion of voids or interstices between the grains, the less cement required, and consequently the more economical the sand. The proportion of voids may be determined by filling a vessel with sand and then determining the amount of water that can be put into the vessel with the sand. This quantity of water divided by the amount of water alone which the vessel will contain, is the proportion of the voids in the sand. The quantities of water may be determined by volume or by weight. The impression that sand of uniform sized grains makes strongest work is wrong. Experience has proved that the greatest strength with the least possible cement is obtained by the rescreening of sand in different sized grains, as this mixture has the least possible voids, while finer sand has more voids than the mixed. The usual specifications for sand for mortar are that it "shall be sharp, clean, and coarse." To these requirements should be added a fourth, viz., the proportions of voids should be as small as possible. Sharp sand is often difficult to obtain, and the requirement that "the sand shall be sharp" is practically a dead letter in most specifications. The sharpness of sand can be determined approximately by rubbing a few grains in the hand or between the fingers, or by crushing it near the ear and noting if a grating sound is produced. All sand does not necessarily need to be sharp, but the sharper the sand the sounder the work. Sharp silica sand is always the most preferable ; it is best obtained by crushing silica stone, thus producing a clean article. Sand employed in actual work frequently has five per cent to eight per cent of suspended matter.

Sand should be clean, that is, free from earthy matter, and other foreign substances or impurities; it should be sharp, that is, the particles should not be rounded or water-worn, but angular or gritty; if necessary it should be repeatedly washed to free it from impurities, until it becomes bright in colour and feels gritty or sharp when rubbed between the fingers. The washing of sand is a simple but somewhat tedious operation ; it can easily be done if a good supply of water is available. One method is to provide a tub of suitable size and to convey a lead or iron water pipe over the side of the tub and carry it down inside nearly to the bottom; the pipe should be provided with a tap in a suitable position so as to avoid waste of water. The sand is washed by two labourers, one holding a sieve over a tub, and the other feeding the sieve with the unwashed sand; as the sand is sifted into the tub of water it sinks and is met by the rising water, which carries all the fine impurities over the edge of the tub. Another method is by placing the sand on a wire screen and playing upon it with a hose, or by placing it in an inclined revolving screen and drenching it with water. Another method of washing is by shovelling the sand into the upper end of an inclined V shaped trough and playing upon it with a hose, the clay and lighter organic matter floating away and leaving the clean sand in the lower portion of the trough, from where it is removed.

A difference of opinion seems to exist as to whether a small percentage of clay in sand will, or will not, materially decrease the strength of the mortar. It is said that in some cases clay to the amount of 10 per cent of the sand did not decrease the strength of mortar, but this statement is somewhat doubtful, as it is generally recognised that a very small percentage of clay has great effect in making a poor cement mortar or concrete, and a small variation in the amount of sand or gravel will also convert it into an inferior material. Cleanliness is an important factor in the making of cement mortar or concrete; not only must the sand be clean and free from clay and foreign particles, but the water also. And in the case of concrete, the quality and cleanliness of the gravel or stone has much influence on the finished work. The gravel or stone should be clean and hard, and soft, friable stones avoided as much as possible. The dampness of the sand is also a matter of importance. If the sand is very damp when it is mixed with the cement sufficient moisture may be given off to cause the cement to set partially, which may materially decrease its strength. This has been found to be particularly noticeable with quick setting cements. Generally for the best results the sand should be practically dry. Ashes as a substitute for sand are not suitable for use with cement, as they render the mortar very weak and porous. Sand loses one-third of its bulk when made into mortar.

Although a sharp course, Thames sand is sometimes preferred for guaging cement, it has been found that the best results have been obtained by using clean, sharp pit sand. For durability, a hard-grained sand is preferable to a soft one, whilst for strength a moderately coarse sand gives the best results. This is probably due to the fact that the smaller the grains are in a certain volume of sand the greater is the superficies over which the film of cement has to be spread in order to cause every particle of sand to adhere. Fine drifted sand is quite unfit for making mortar, the addition of water making it somewhat like mud, besides taking a larger quantity of cement. Lime without sand mixed with it is useless as mortar, as it sets or hardens so slowly ; the addition of sand at once makes the mixture of a porous nature, and the carbonic acid from the atmosphere obtaining access to the lime, sets up a chemical action and causes the mixture to set or harden. The admixture of sand with lime prevents the contraction of the latter, the action or process of setting causing pure lime to contract largely in bulk; when converted into mortar it loses one-third if its bulk.

Portland cement used without sand is exceedingly strong, which for all ordinary purposes is quite unnecessary. The addition of sand when used in the proper proportions does not unduly reduce the strength of the mixture. Sand is also added for economical reasons. Sand is extensively used as an aggregate in Portland cement for moulding and plastering. The word "aggregates" in concrete making applies to any coarse material sufficiently sound and hard to admit the adhesion of cement to its surface, and by proper proportioning much expense may be saved without injuring the strength of the finished product. Gravel is the most commonly used "aggregate" but crushed limestone, furnace slag, and brickbats are often substituted with good results. Although the addition of sand to concrete ensures a more solid mass, the real value of its strength depends almost entirely upon the matrices or cementitious material employed. The size of the grains of sand does not greatly influence the strength of the mortar, but when composed of smooth round grains it is apt to weaken the mixture in which it is employed.

There are many available substitutes for sand, but they must all be crushed under rollers in a suitable mill until they are similar in size to grains of sand, and (if thought necessary) should afterwards be screened through a sieve of small mesh to remove the dust, and afterwards washed if for important work.

Any siliceous matter in the form of rough angular grains, free from matter capable of fermenting, and from matter soluble in water, can be used as a substitute for sand in lime or cement mortar or concrete. Granulated furnace slag is often used, but owing to its proper nature it can never be classed as a sand, and more cement or lime is required than in any other substitute. Granulated slag is of a yellow and sometimes of a light cream colour. Crushed basic slag is not a very desirable substitute for sand as it contains too much iron, it is of a blue or blue black colour, and is very easily distinguished from granulated slag.

The London County Council bye-laws allow the use of burnt ballast or broken brick as a substitute for sand. Crushed bricks and thoroughly burnt clay ballast yield strong mortars, stronger in some cases than ordinary sand. "Ballast" (or burnt clay) is an excellent substitute for sand in the making of mortar, but it must be thoroughly burnt. The clay, after being dug out, is exposed to the sun for several days, and is then heated up over a fireplace roughly formed with bricks and intermixed with coal. A fire being lighted in the fireplace, the clay must be thoroughly burnt, the pieces being afterwards ground to a size similar to grains of sand. Ballast is used even in high-class work with satisfactory results. Crushed shells make a very desirable sand substitute, but are only obtainable along the coasts, and when used with a very light-coloured cement, make a very good imitation of white marble ; shells of a soft nature, usually found in lakes, are not really shells but marl, and are too soft to be used as a sand substitute. Among the many substitutes may be mentioned ground pottery, coke breeze (except in damp situations), smithy ashes, furnace slag, scoriæ, and similar substances of a hard gritty nature ground small enough. In some districts the use of sand for making mortar is practically unknown, furnace ashes being used. The "jerry-builder" often adds to the above list of substitutes by using road sweepings, garden mould, ashpit refuse, etc. In some neighbourhoods the finding of sand upon the site would be a great consideration, whilst in others it would not be considered valuable at all, as it could probably be purchased cheaper than it could be dug. In certain districts siliceous products are found which may be used partially or wholly as a substitute for sand, having the property of forming a hydraulic mortar when mixed with lime which are too pure for use in ordinary lime mortar. Such deposits are generally known under the term of "pozznolana," but in some districts it is known under the names of "trass" and "arenas." Strictly speaking, it is a volcanic clayey earth found in the neighbourhood of Pozznoli, near Naples. Artificial pozznolanas are sometimes manufactured by calcining clays of suitable composition at a low temperature.

The proportion of sand for lime or cement depends somewhat on the purpose for which it is to be used, but it is of the greatest importance that the materials should be combined in such proportions as to produce the greatest possible density, and should be accurately measured before being mixed. The sand should be first measured, and spread on a wood platform. The cement being emptied into a hollow formed in the middle of the heap, and the two ingredients should be thoroughly mixed *before* water is added. The proportion of sand to cement or lime for mortar is generally from 1 to 2 to 2 to 4. The proportion of sand to lime for plastering is somewhat difficult to determine; generally speaking one part of lime to two parts of sand are the usual proportions, but it will vary considerably according to circumstances. The cheapness of sand is also a great inducement to increase the proportion of sand, and thus cheapen the plastering to its detriment. All sand to be used for plastering first-class work should be washed, and the finer the plaster is required the finer the sand must be. Coarse sand is most suitable for "coarse stuff," fat limes and Portland cement for floating. Fine sand is best used with hydraulic limes. The light colour of most river sand influences its use for internal work with white cements. The function of sand in plastering is to produce a regular shrinkage, and prevent any excessive shrinkage which would result in cracking. It is also used to form channels for the crystallization of the limes. The chief cause of saltpetreing in plastering is the use of sea salt or salt water which being acted upon by the atmosphere causes saltpetreing. The only remedy is to avoid the use of material containing salt. When ashes from iron works are used as a substitute for sand, they frequently contain particles of iron which causes rust marks to appear on the plastering.

CHAPTER II.

Clay and Its Analysis.

It is only when a nation has arrived at a certain degree of opulence and luxury that a just appreciation of the means and materials by which such a position has been attained may be said to exist. Clay has been made use of by man even in the most primitive times ; but the ages that have elapsed, and the distance by which we are separated from the people that first used it, deprive us of the means of ascertaining to what extent it was formerly used. But it has proved that the first habitations of man were formed of branches of trees and clay. The first houses of the Greeks were only of clay ; and it was some considerable time before they were acquainted with the process of hardening clay into bricks. The Abyssinians still build with clay and reeds. It is generally agreed that clay in the form of bricks and tiles was employed in the art of building for a considerable time before stone was used.

The use of burnt clay in some form or other in nearly all classes of modern buildings is more extensive to-day than at any other time in the history of the building trades ; and, like all other building materials, in the hands of ingenious craftsmen, clay is directed into many different channels of usefulness. Its strength is not questioned, and it can be readily beautified in form and colour. Clay may be said to be the primary basis of the principal materials used by builders, viz., bricks, tiles, terra-cotta, and pottery; it also is largely used in the manufacture of cement.

Clay is the term usually applied to any earth which possesses sufficient ductility to admit of its being kneaded with water. Practically the term clay includes the whole of the naturally occurring plastic materials which have all a similar composition—essentially consisting of a hydrated silicate of alumina. Common clays may include the great majority of clays used in the making of ordinary bricks. The colours of the different varieties of clay vary, white, cream, and various shades of yellow or grey being common, and some are black. Blue or green clays are also sometimes met with. The yellow clays derive their colour from the hydrated peroxide of iron, which forms the red oxide of iron on burning which produces a red brick, or, if the heat is very high, it causes partial vitrification, changing the colour of the brick to a bluish grey. The colour of the grey clays is due to coaly or vegetable matter, which burns away in the kiln, producing a white brick. When fired, black clay usually loses its colour more or less completely by the organic matter being destroyed, white clays become perfectly white, whilst the colours of the coloured clays is generally rendered more vivid by the action of the fire. Clays, therefore, may be said to be characterised by no special colour. The pure variety is white, but they more commonly occur grey, drab, bluish, and often mottled and variegated. In fact, they are found of almost all colours, frequently being brilliantly tinted with reds, yellows, and purples. Organic stains give a variety of colours, often of the most brilliant in hue, purple and red being the most striking.

Different compounds of iron (the most common colouring causes) give greenish grey, yellow, brown, and red tints. The colours are deepest when the clay is moist, and they grow lighter as the clay is dried. The colours affect the use of the clay in its raw state ; as, for example, its use in the manufacture of wall papers, the adulteration of foods, etc. In most cases its colour, in the natural state, enables us to confer the colour the burnt product. Organic stains, however, disappear on burning, while the iron stains are modified or developed by both the intensity of the heat employed, and the degree of oxidation effected in the process of burning. Natural supplies of the best china and blue ball clays are confined almost exclusively to Cornwall, Devonshire, and Dorsetshire. Similar deposits have been found elsewhere, but not on a sufficient scale to justify their commercial development. The pottery industry is largely centred in Staffordshire, where there are at least 500 potteries, while those in other counties number little more than 100 collectively. It seems anomalous that Staffordshire should be the centre of the pottery industry when the supplies are largely to be found in the West of England, but the reason is that coal is cheap in the former district, and that it is less costly to bring the raw clay to the coal than vice-versa. Ball clay is delivered in the potteries from the South-west of England at about 30s. a ton, and of this 14s. is represented by carriage. It is said that Ball clay can be shipped from Dorset and Devon 500 miles up the Rhine to Germany at less cost than it can be brought via Runcorn to the Potteries. The superior quality of British fireclay goods is chiefly due to the excellent quality of the raw material furnished by the districts named. This fact is so well known, that the rumour of an American scheme to " corner " the mines recently caused quite a scare amongst the pottery manufacturers. Yellow-ware is produced to a certain extent in Burton, and Newcastle-on-Tyne. Earthenware is also made in Glasgow, and by a few firms in Yorkshire, whilst Bristol furnishes stoneware. All these are dependent upon Cornwall and Devon for their raw material, with the exception of the yellow-ware firms, who are able to obtain the greater part of their supplies from local sources. For pottery, a plastic clay, tough and elastic is needed; the commoner London clay makes very good ordinary pottery. The preparation of the clay needs more care than for bricks, or tiles, the preparation largely depends upon the clay itself, and what form or class of pottery is to be produced. Potters' clay includes many varieties of plastic clay which are used in the manufacture of pottery-ware, being very tenacious, easily moulded, and infusible. It is comparatively pure plastic clay, free from compounds which imparts colour to the clay when burnt, although potters' clay contains iron, the proportion is so small that the clay is perfectly white after being fired. Smectic clay or fuller's earth is not used for pottery. Ochreous or ferruginous clays are not used for pottery but for colouring matters only. Kaolin clays are white generally, crystallized, refractory, and undergo no contraction in firing. Refractory clays are yellowish or greyish white, soft and greasy to the touch, forming with water a tenacious dough, like a supple paste. Figuline clays or " potters' earth " are plastic and coloured, generally becoming red in baking, and much more fusible than Kaolin and the refractory clays, most of them containing about 2 to 3 per cent of limestone. Clayey marls or effervescent clays, are of a variable plasticity, very fusible, and contain a considerable amount of limestone, which effervesces if treated with acid. They are called " clay marls," or " calcareous marls," according to the amount of limestone they contain. "Lehm," "Tableland slime," or brick earth is a mixture of clay and very fine quartz, coloured yellow or red by oxides of iron, when calcareous "Lehm" is called "loess."

There are few counties in England whch do not produce minerals employed in the manufacture of bricks, and the strata from which they are dug belong to various geological ages. Beginning with the coal measures, we have mines and quarries producing fireclay on a very extensive scale. Permian strata are likewise largely worked, as well as various beds in the Triassic, Jurassic, and Cretacious rocks. The Tertiary beds of the South of England afford much clay for making bricks, tiles, and pottery. The china clay of Cornwall and Devon is derived from granite decomposed in situ. Surrey yields fuller's earth, which there occurs in the lower greensand. A like mineral is obtained in Somersetshire from beds of Jurassic age. The pilocene clays—that is the most modern tertiary deposits, or the series of strata overlying the chalk and beneath the quaternary or recent ; they are divided into Eocene, Miocene, and Pilocene clays—of England, are represented in Ireland by the clays of Lough Neagh. The tertiary clays, sands, gravels, marls, and limestones are represented in turn by basalt sheets, beds of volcanic earth, and lacustorine formations of iron ore.

Clay is the term generally applied to any earth which possesses sufficient ductility to admit of its being kneaded with water. Common clays may be divided into three classes, viz., unctuous, meagre, and calcareous. The first named is chiefly used for pottery, and the two latter for the manufacture of bricks and tiles. A recent investigation showing the number of varieties of clay that exist proved that in a bed of clay near Poole, Dorsetshire, upwards of 500 distinct sorts are to be found.

The earths, or clays employed in the manufacture of bricks may be divided into three classes as follows :—

(1) Plastic or " strong " clays, or as commonly called by the brickmaker, "foulclays," and also " pure clays," which are composed of silica alumina, and a small proportion of lime magnesia, soda or other salts.

(2) Loams or mild clays, which consist of clay and sand, and are consequently often designated " foul clays."

(3) Marls or calcareous clays containing a large proportion of calcium carbonate $Ca\ Co_3$.

Clays are usually characterised by a peculiar odour or " arquillaceous smell," which is not invariable, and by a smooth unctious feel, which is also frequently absent, being dependent upon the fineness of the grain and the absence of coarse impurities or grit. In density, hardness, tenacity, etc., clays differ widely, being modified in these particulars by their geological history. Among the crystalline rocks where they originate they are apt to be coarse and loosely adherent, but often transportation and secondary changes which they may have undergone, following their accumulation as sediment, such as compression, the loss of water, infilteration of mineral matter, etc., changes their general structure widely. They vary from soft, porous, incoherent masses, though tough, compact varieties, are often laminated, or have a fissile structure.

Amongst the suitable earths for brickmaking is the pure white clay called ' kaolin ' found in Cornwall and Devonshire, formed by the decomposition of the Felspars of the granite rocks in the neighbourhood, which is washed down into the rivers, and forms a milky white deposit. This clay is, however, far to valuable for making common bricks, and is used for porcelain and glazes. Chinese tradition says that the making of porcelain began about the year 2697 B.C., but it is thought that the ware produced then was only of a common glazed kind, and that the time of the beginning of porcelain was somewhere about 202 B.C. and A.D. 220. It was not until the eighteenth century that the Chinese method of making porcelain became known to other nations.

Earthenware is made from ordinary clay as used for making bricks, tiles, etc. Stoneware is made from clays of the lias formation, mixed with ground pottery, or sharp sand. When the articles are glazed it is difficult to distinguish them apart, and even when they are fractured some skill is required to tell one from the other.

Some clays belong to the class commonly known as 'flint' clays, and are mined only by drilling or blasting. The degree of hardness varies in the scale of ten used by mineralogists, from one to 3.5 ; but this is hardness of the clay mass technically a rock, and not that of the individual clay or kaolinite particles, the hardness of which has not been accurately determined owing to their extreme smallness. The specific gravities range from less than one to about 2.5, pure kaolinite having a specific gravity of 2.60. The specific gravity, of course, varies with the state of compactness of the mass.

The properties and characteristics of clay depend upon first the kaolin minerals, and second the impurities. In the case of the former, the conditions in which their fragments are found is important—

that is, whether their individual particles consist of prismatic crystals, minute plates, or thin cleavage scales resulting from either the simplest form of disintegration of the original crystal, such as is brought about by the action of the frost or by abrasion, suffered during transportation from its place of origin to its home as a sedimentary deposit. In the case of the impurities, much depends upon both the absolute and the relative quantities of division.

Amongst the principal impurities found in clays is silica ($Si\,O_2$), which exists in more or less quantity in all clays, principally combined with alumina as silica of alumina, or in an uncombined state in the form of sand. Free silica or sand is a most useful constituent of clay; it reduces its plasticity, but it also reduces the shrinkage that occurs during the process of burning the bricks in the kiln. Within certain limits, the larger the proportion, without being excessive, of sand present, the more uniform and equable in texture will be the bricks or other article manufactured be, but an excess of sand in the clay will cause the bricks or other articles to be too brittle or deficient in strength. Free silica, in the absence of fluxes, or even in the presence of alumina, when no other constituent is present, is infusible at ordinary brick-making temperatures, hence the more sand a clay contains then the more infusible it should be. But should silica be present in nearly equal quantities, the presence of a small quantity of oxide of iron will cause the clay to be fusible at a comparatively low temperature.

Nearly all clays contain small quantities of common salt (sodium chloride). Clay found near the sea or near salt deposits, sometimes containing it in considerable quantities, which renders the clay unfit for brick-making, the bricks being liable to twist and warp when fired. When existing in small quantities, however, it acts as a powerful flux, and possesses the property of being voltalised by the heat of the kiln, and, whilst in this condition, it carries with it, in a volatile state, various metallic compounds such as iron, and acts as fluxes. Bricks made from such clays are never entirely free from hygroscopic moisture. Carbonaceous or organic matter when existing in clay to great extent is detrimental to its use for brick-making, as it is sometimes difficult, especially in a dense clay, to burn them completely out, with the result that the bricks are liable to pass out soluble compounds, and discolour any plaster or stucco work put on them. The bricks are also a different colour internally, and will not stand cutting for face work. Alkalies, potash and soda, are detrimental to clay as a material for brickmaking, if they are present to any great extent, as they act as a flux and cause the clay to melt and become shapeless. The presence of iron pyrites (sulphide of iron) will result in the pyrites becoming partially decomposed during the process of burning, and will oxidise in the brick, and in doing so will crystallise and split the brick. They are often found in clays and should be carefully picked out.

The oxide of iron which colours clays with various tints make them fusible by reason of formation during burning of silicates of iron. The most refractory clays are those which are nearly pure silica of alumina ; the presence of metallic oxides, such as oxides of iron, lime potash, soda, etc., make clays fusible by reason of the formation at high temperatures of complex silicates, which are all more or less fusible. Calcareous or fusible clays require special care in the kiln in order that the product may be uniformly burnt. Some clays will melt at 1800 degs. Fahr., whilst others will not melt at 2800 degs. Fahr.

Some clays may resist heat but lack toughness, they become brittle, and, therefore, unsuitable for several purposes. Others again can be burnt with great quantities of sawdust, and are wonderful non-conductors, but are too soft and are not suitable for resisting severe strains. When clay is of a close texture, either from extra manipulation or from its natural qualities, it is generally necessary in the manufacture of most articles, and especially so in articles of large size and varying thickness, to mix with a certain proportion of rougher grained and previously burnt clay to prevent it cracking. Cracks in bricks are a source of weakness, and by reason of the porosity of bricks water may lodge in the cracks, and, becoming frozen, burst the brick asunder.

Some clays are improved by the process of weathering, which breaks up the hard rocky lumps, exposing the interior to the washing action of the rain ; it also mellows and disintegrates the particles, thus making it valuable in the preparation of clay for special purposes; in the case of fireclay it greatly assists in rendering the hard material more easily crushable in the crushing mills. The Romans tempered their clay through a period of from three to five years, whereas to-day bricks are frequently made from clay that has never been tempered at all. The result of using untempered clay is that the soluble salts are included in the bricks, and breaks them up by efforescence, and destroying the cohesion.

Different kinds of clay do not all shrink in the same proportion in drying and burning. Pure or strong clays shrink most, and the weak or impure clays the least. The contraction of the pure clays is remedied by the addition of sand, or crushed burnt brick. Fusible clays undergo shrinkage in the firing because the particles weaken and approach one another to form a homogeneous mass. This contraction causes warping and cracking, and as dry clays are free from this defect, the tendency is to work the clay dry, but this dry method in the manufacture of tiles is inclined to produce lamination. Plastic and fusible clays undergo much contraction ; the former because they contain a great deal of water, and suffer the greatest shrinkage at about 110 degs. the moment they lose the water.

The plasticity of clay is one of its most important features, the plasticity consisting essentially of a hydrated silicate of alumina, which is one of the principal constituents in nearly every kind of clay, and which gives the material its plastic qualities. The plasticity of clay is one of the greatest factors in brick-making, and is a phenomenon which has hardly been explained yet. Ordinary clay, such as is used for the manufacture of bricks and commonly spoken of as plastic clay, loses its cohesive properties if dried sufficiently to remove nearly all its moisture, if water is afterwards applied in considerable quantities it becomes almost liquid mud. On the other hand, clay which has not been so dried will not absorb more water and will lose some of its outside particles only in the washing. Generally the pure clays are the most plastic, and the presence of sand or lime simply reduces their strength as they are quite inert in this respect. Pure clays shrink and warp to a considerable extent on burning, and as the presence of sand and lime prevents this to a great extent, their presence is rather an advantage. Bricks made from pure clays are almost infusible, and are therefore admirably adapted for furnace work. The addition of sand to pure clays tend to make the bricks still more infusible and at a high temperature the grains of sand lose nothing, the bricks keeping their shape by the sand forming a support for the clay in shrinking. Clay when heated to redness loses its combined water and changes its physical character. It cannot be again made plastic by admixture with water, though it may be used as a substitute for sand in brick-making and mortar.

"Egyptianised clay" is a method of treating clay and other earthy materials with tannin, so as to ensure greater strength in the ultimate products, to reduce the shrinkage and warping in the process of drying and baking, and to increase the solubility and the plasticity of the material. Non-plastic clays may be rendered plastic, and the plastic clay made more plastic by treatment with tannin, or with an agent having astringent tannin principles. The clay so treated is changed in a most remarkable manner. With the addition of 1 per cent of tannin, 13 per cent less water is required to make the clay soft. The greatest effect is obtained by the use of 2 per cent of tannin in a ten day treatment. The treatment consists merely in keeping the clay wet with water, so that the tannin is dissolved. In the burned form the strength of the clay is increased 50 per cent, while in the sun-dried form it is increased in tensile strength 350 per cent. The treatment removes the cracking tendencies of many clays, and there is less shrinkage. All parts intended to carry loads may be greatly increased in strength, while there is decreased porosity. As the sun-dried clay is made stronger than the burnt article, there is said to be a big saving in fuel. In making glass pots, it now takes months to 'age' or temper the clay, while by treating the clay with tannin the maximum effect is obtained in ten days.

It is seldom that a clay can be used without admixture with other substances. To thin rich clays antiplastics are used, such as sand, chalk, clay marls, and in general thin clays, cinders, coke dust, sawdust, etc. Rich clays cannot be used alone on account of their eminently plastic properties causing the clay to stick too much to the moulds or cylinders of the machines ; and the paste they form with water falls in and loses shape after. The very tenacity of rich clays prevents equal drying in all parts, which causes cracking. The Babylonians and Assyrians mixed and blended their clays, bringing parts from a distance, so as to get a suitable combination of texture and colour. The blending and composition of clay has been the subject of much research, and we now know that the methods of the ancients were similar to those now adopted by most modern manufacturers.

Occasionally the different beds in a clay pit vary so much that it requires a mixture of two or three different beds before an earth suitable for brickmaking can be obtained. Pure clays require the addition of lime for a flux and to bind the earth. Very few brick earths or clays are in such a condition as to allow of their being used without some special preparation. Strong clays require the addition of silica and lime. Loams, or mild clays generally contain an excess of sand, and require the addition of lime. Marls or clays containing a large proportion of lime make very good bricks, and are frequently used without the addition of other substances. An artificial malm is frequently used consisting of clay and chalk mixed.

The refractory nature of any clay is due to silica being present in large proportion, and alkaline matter in small proportion. Such clays are difficult and expensive to work, as they require long and continued firing, so that they are thoroughly burnt throughout.

Silica is frequently found in clay in combination with lime in a soluble condition, which is very detrimental, as it absorbs moisture and causes the bricks to swell even after being built into walls. Small portions of limestone often form an objectionable feature in field-made bricks; the limestone becomes caustic by the heat imparted in burning, and when the brick becomes damp each portion of lime is slaked and expands, frequently bursting the brick, or leaving large holes.

An excess of lime will cause a brick to 'run' and lose its shape. Ordinary building bricks are made of clay and other earths, which are treated in various ways, formed to the shape in moulds, and burnt. Lime acts upon clay in two ways; one effect is that it diminishes the contraction of the bricks during drying, the other effect is that it acts as a flux during the process of burning, and causes the particles of silica to melt, and thus binds the clay together. Clays may be tested for the presence of limestone by heating the clay with a small quantity of diluto hydrochloric acid. The presence of limestone will cause an effervescence.

The practice of adding lime to increase the fusibility of clay, or the use of clays containing a considerable proportion of limestone is largely responsible for the lamination of roofing tiles, the specks of lime becoming slaked by moisture splits the tiles. This can be remedied by hard firing so as to unite the lime with the silica and alumina, but this has a tendency to produce a deeper colour, some of the tiles being purple instead of red. This defect is technically known as

'Limewash.' Carbonate of lime, or limestone, though refractory itself when pure, renders clay fusible when mixed with it. There should not be more than 10 per cent of limestone in any clay.

Clay enters largely into the manufacture of cement. The greater quantity of it is obtained from the alluvial deposits, known as 'saltings,' in the estuary of the Thames and Medway. At the latter place, the material is obtained sometimes by hand filling into barges or lighters, and sometimes by steam cranes, afloat on lighters, dredging clay from below water level. At the former place the inner part of the 'saltings' is worked in the absence of water by steam diggers or navvies.

The great force exerted by the expansion of clay is often unpleasantly realised by the appearance of cracked walls. An 18 in. layer of clay in a foundation has been known to lift the chancel of a church bodily. The expansion of clay takes place to a greater extent near the surface, where it more readily becomes dry and moist according to the weather, than at a depth of 5 ft. or more from the surface. The expansion of clay may be caused, however, not only by moisture, but severe frost.

Puddled clay for embankments, reservoirs, etc., is made from clay free from sand, roots, or vegetable matter, or soft friable stone, and spreading it out so as to be 'tempered,' or affected by the weather as much as possible. The longer it is exposed to the action of the weather the better. When required for use it is mixed up with water if necessary, so as to form one compact, homogeneous, water-tight mass. Puddled clay will be less liable to crack if mixed with gravel in the proportion of 1 to 1, or less, according to the nature of the clay. The best clay for 'puddle' for waterworks, or other similar constructions, is the bluish grey clay, common in the carboniferous formations of the mining districts. Some of the yellow clays are also very good, but the worst clay for the purpose is the Devonshire potters' clay, known as kaolin, it being the disintegrated felspars of granite rock. To test clay for its suitability for 'puddle,' a piece about 1 in. diameter may be rolled to about a foot long, and if it will support itself without breaking when held by one end, it may be classed as good for 'puddle' making.

In the building regulations of New York, when no actual test is demanded, the sustaining powers of various soils are taken as follows :—Soft clay, one ton per square foot, ordinary clay and sand wet and springing, two tons ; loam clay and fine sand, firm and dry, three tons ; hard clay, four tons. Under ordinary conditions clay will carry safely not more than three tons per square foot, although London clay in deep foundations has been known to carry five tons per square foot. London clay is not usually reached at less than thirty feet from the surface of the ground in London. For a short space of time, it is possible to leave stiff clay with a vertical face of 10 ft. or 12 ft. in depth, but the effect of alternate wet and drought will soon reduce this to the natural angle of repose of the material, namely, well drained clay 45 degs., wet clay 16 degs.

Economy in manufacture is of primary importance, 30 feet below the surface or normal level is the maximum profitable depth of working clay for ordinary bricks, and the fact that the material is 300 feet deep does not increase its value. Approximately 1 acre, 1 yard deep, will make two millions of ordinary bricks ; 10 yards deep 20 millions. Economy of fire consumption is another consideration ; the old fashioned Scotch kiln consumes from

8 to 11 cwts. of coal per 1000. In the intermittent kilns the coal consumption is much less, being 5 to 8 cwts. per 1000. The introduction of the Hoffman kiln secured the fullest economy in fuel, and there are now many kilns in existence with a consumption of coal as low as 3 cwts. per 1000 bricks. There are also gas fired kilns for use where high temperature and perfect control are desired, and the cost per 1000 bricks is said to be very low as compared with coal. In digging clay for brick-making, it frequently happens that a great deal of earth at the top has to be thrown aside as useless, because it is mixed with sand and stones, and, consequently, the excavation has to be carried down till a bed of true clay is reached. Many devices have been tried for dealing with this upper ground or 'bearing,' but the only really satisfactory machine is that introduced recently by Mr. J. S. Wilkes.

Terra-cotta is made from pure clays capable of withstanding vitrious heats, and is thoroughly vitrified and practically imperishable. A true terra-cotta clay which will vitrify and approximate to a stoneware, must, from its nature, be one with a large shrinkage and tendency to warp. A loamy or sandy clay, with little shrinkage, can only burn to a soft unsound and porous material, unfit to be called terra-cotta. It is therefore necessary to control this shrinkage and warping during the process of drying and firing, particularly in blocks of large dimensions; this is sometimes done by incorporating previously burnt and ground clay of the same variety, where possible, as that used in the body of the block, in proportions suitable for the class of work.

Terra-cotta is generally made from clays of the tertiary beds, or from those occurring above the chalk, or those in the oolite and lias formations.

Great care is exercised in the selection of the clay and the combination of the materials which is mixed with it, after it has been cleaned of all impurities. The clay is sometimes mixed with sand, crushed grass, old pottery ware, and also flints, and moulded and pressed into the desired form, and burnt in the kiln. The most suitable clay for terra-cotta is that containing from 60 to 65 parts of silica to about 28 parts of alumina. It is found in many districts, viz., Tamworth, in Staffordshire; Watcombe, in Devon; Poole, in Dorset; Everton, in Surrey; Ruabon, in North Wales; Rowley Regis, and also in Northamptonshire and Cornwall. That found at Tamworth comes from the coal measures, and is used for making buff terra-cotta, which is the hardest colour to obtain in a uniform tint, requiring a thorough acquaintance with the clay, and its action during the process of firing. A wash of the desired colour is sometimes given the clay before it goes into the kiln, but it generally wears off after a year or two, and is not a method to be recommended. Fine clays with little preparation are largely used for terra-cotta, but do not produce such good results as the mixed clays. The addition of sand or broken pottery ware to the clay makes the terra-cotta harder. Clay containing 8 to 10 per cent of oxide of iron is extremely fusible and difficult to burn successfully, and its fusibility is increased by the presence of lime, magnesia, and other impurities. In making terra-cotta from the refractory clays, a sufficient amount of iron oxide to burn it to a good red colour is sometimes added. The large amount of silica, and the small percentage of alkaline matter present in the clay is the cause of the refractory nature of terra-cotta; the presence of alkaline matter produces the vitrified surface to which terra-cotta owes its durability.

Fireclay is a clay which when subjected to high temperatures does not melt or become soft. Dinas fireclay possesses the peculiar property of expanding when subjected to high temperatures. Dinas rock, from which the Dinas firebricks are made, occurs in conditions varying from a firm rock to disintegrated sand, and the addition of about one per cent of lime is necessary to make it into firebricks.

The peculiar advantage of fireclay as a material is due to its extraordinary power of absorbing heat, and of gradually radiating the same in such manner as to produce and maintain for a great length of time an equable temperature. The heat-resisting power of a clay depends not only on its chemical composition, but on the mechanical and physical condition of its ingredients. Silica, alumina, and lime are each separately very infusible, and are capable of resisting very high temperature without softening, but for various reasons they cannot be used separately.

The following is the analysis of a highly silicious and highly refractory fireclay :—

Silica	76·63	per cent.
Alumina	17·31	„
Oxide of iron	0·90	„
Lime	0·16	„
Magnesia	0·10	„
Alkalies	0·21	„
Organic matter	4·50	„
Moisture and loss	0·19	„
	100·00	„

The following analysis is that of firebricks noted for their non-expansion under high temperatures as well as for the usual qualities to be found in firebricks of high quality :—

Silica	62·10	per cent.
Alumina	33·10	,,
Ferric oxide	3·00	,,
Lime	0·90	,,
Magnesia	a trace	
Potash	0·90	,,
	100·00	,,

The following analysis taken from Greenwood's 'Steel and Iron" may be taken as an example of good fireclay :—

STOURBRIDGE FIRE CLAY.

Silica	63·30	per cent.
Alumina	23·30	,,
Potash	—	
Soda	—	
Lime	·73	,,
Magnesia	—	
Water combined ,, ,, hygroscopic Organic matter	10·30	,,
	99·43	,,

Fireclay is usually described as being a hydrated silicate of alumina, that is, it is a compound of silica and alumina with some water in the combined form. Any other bodies present in addition to those act as impurities and so lower the point of temperature at which fusion takes place. This is especially true of soda or potash, and in a less degree, of oxide of iron and lime. The greater the proportion of alumina the less fusible fireclay is, and the less subject to the cutting action of slag.

Fireclay is plastic in proportion to the fineness of the particles and the percentage of alumina. The principal objection to fireclay is the great shrinkage which takes place while passing from the plastic to the burnt condition.

Fireclay includes many infusible clays, which are used for the manufacture of heat-resisting apparatus, such as gas retorts, firebricks, crucibles, and glass house pots. Fireclays are almost free from alkalies, lime, and iron, and for that reason withstand heat well. They usually occur beneath a seam of coal, the two being worked together, hence they are known as "underclays." Clays for making firebricks should be free from such impurities as lime, alkalies, and oxide of iron, as at a high temperature these impurities form a fusible compound with the clay. This disadvantage is of no account in the case of common bricks, as an incipient fusion may render a weak clay stronger. When impurities, however, are present in an excessive degree, the heat may become fused into a clinker, if the temperature is too high. Vitrified bricks are formed in this manner by partially fusing in a reducing atmosphere at a high temperature. The fire-resisting qualities of a firebrick are only to be obtained by the presence of certain proportions of silica and alumina, chemically combined with water. Natural fireclays are hydrated silicates of alumina, their plasticity depending on the water in their composition. The fireclays most extensively used in England contain a large proportion of free silica. The nearest approach to the use of silica by itself as a firebrick are the well-known Dinas firebricks, which contain more than 98 per cent of silica.

Fireclay is found abundantly in the coal measures and mill-stone grit of the carboniferous group ; it is a stratified rock, hard, and compact, blasting powder and dynamite having to be used in the operations of mining it. Firebricks are also made from the siliceous clays found amongst the granite deposits in various parts of Devonshire. Their heat-resisting power is largely due to the coarseness of the particles of disintegrated granite in their composition.

Fireclay after being mined is taken to the crushing mills, and crushed by means of powerful machinery, and then conveyed to the wet mills, where it is made plastic or tempered with water, and moulded to the required form, and set out to dry before being burnt in the kilns.

Six or seven feet is a very common thickness where fireclay is mined alone; in some cases it varies in thickness from one or two feet to thirty or forty feet. The system adopted in working it is the "pillar and stall," and the "stoop and room." It is frequently mined in conjunction with a seam of coal. Fireclay, in some districts, is found in a succession of basin-formed deposits, which differ much in quality, close proximity being no guarantee that the qualities of one bed will be maintained in that of its immediate neighbour.

Two other substances, which are not true clays, are used in the manufacture of firebricks, etc. There are the Dinas earth, which occurs in the Vale of Neath, and from which the celebrated Dinas bricks are produced ; it consists of almost pure silica. The other is Ganister, a kind of red sandstone occurring in the lower coal measures. Both of these substances are used for fire-resisting purposes. It is stated that a Suffolk brick-making firm, after experimenting with the dredgings of the river Stour, finds that excellent firebrick can be made from it.

The principal qualities required in a firebrick are, infusibility under high and sustained temperatures, and non-liability to crack and split when subjected to sudden changes of temperature, and to be able to resist the action of melted slag, copper, and other materials. Firebricks are required to resist exposure to intense heat, as in blast furnaces, gasworks, retort benches, etc., for periods of weeks or months continuously.

It often happens that two brands of firebricks made from clays apparently identical in chemical composition differ widely in their refractory qualities. The shrinkage of fireclay in the process of manufacture varies from ½ inch to one inch in a foot ; this shrinkage should be all taken out in the kiln, hence the importance of hard burning. The contraction of Stourbridge firebrick is about ⅞ inch in the length of a brick.

Firebricks are used whenever a great amount of heat has to be withstood. They are admittedly the best non-conductors of heat we have. The essential point of a good fireclay is that it should contain nearly pure hydrated silicate of alumina: an excess of alumina in proportion to the silica renders the fireclay more infusible. For some purposes firebricks are preferred of a dense and close structure, whilst for some purposes soft burning is preferred to hard burning ; but for general purposes firebricks should be hard burned, and of an open and porous nature. A firebrick having these qualities when subjected to high temperatures in the furnace, acquires a thin glazed surface, whilst under the glaze the brick remains rough, open, and porous, and gradually wears or sweats away perfectly free from any tendency to split, and reflects back the heat of the furnace, a thing that a dense and inferior brick is incapable of. Firebricks are often built raw into furnaces, and burnt by peating the furnace, and so forming a solid lump of fire-resisting material.

The cement used in furnace building is made with fine ground fireclay. Lime should on no account be mixed with the fireclay on account of the action of lime in contact with silica at high temperature.

Well known firebricks come from Blaydon Burn, Stourbridge, Lee Moor, Windsor, Dowlas, Dinas, and Glenboig, the quality in each case depending on the relative proportions of silica and alumina, and freedom from oxide of iron and other alkaline salts, which tend to make the clay more fusible.

Dinas firebricks will stand very high temperatures, but are more fusible than ordinary firebricks, and will not stand so well when subjected to the action of basic substances, such as furnace slags containing a large proportion of oxide of iron.

Firebricks should have, as a first necessity, the quality of not softening at a high temperature. In the second place, they must not disintegrate or chip under the influence of heat, and they should not be readily fluxed by the slag running down them. Excessive expansion and contraction are causes of objection, as likely to cause a shorter life to the cupola or furnace lining, and firebricks for cupola use should be able to withstand quick changes of temperature, from the highest melting temperature to the normal temperature of the atmosphere, without excessive cracking. That firebricks combining these qualities to a very satisfactory degree are available says much for the excellent materials used, and the mode of manufacture employed. Firebricks should always be under cover, and kept as dry as possible. If they have absorbed any considerable amount of moisture, quick application of high temperatures is quick destruction. Often the small service which some firebricks give is due more to bad usage than bad quality. If the firebricks have got wet, a slowly rising temperature, which will gradually drive off the moisture, is a necessary preliminary to good service. Firebricks in casting furnaces, that are in constant use, usually last for about six or seven weeks, but if the furnaces are dabbed with ground up old crucibles and fireclay once a week they will last for three or four months. Furnaces used for casting copper, or nickel, will not last for more than three weeks. Generally speaking, the 'life' of a firebrick depends upon its composition, and the treatment it receives in the furnace. The furnace when first used should be slowly heated for at least a day; a fierce fire immediately after relining a furnace will seriously shorten its life; for a long life the furnace should be ganistered weekly.

The following are analyses of some of the best known firebricks and clays :—

	Silica.	Alumina.	Lime.	Magnesia.
Dowlas	63·09	29·09	·42	·66
Windsor	84·65	8·85	1·90	·35
Lee Moor	75·04	21·25	1·95	·41
Dinas clay	98·31	·72	·22	...
Stourbridge clay	63·30	23·30	·73	...

	Oxide of iron.	Potash.	Soda.	Titanic acid.	Water.
Dowlas	2·88	1·92	·31	·21	...
Windsor	4·25	...	...	...	...
Lee Moor	·37	·83	·09	...	...
Dinas clay	·18	·14	·14	...	·35
Stourbridge clay	1·80	...	...	...	10·30

For lining cupolas for blast furnace or other cuprous slags, nothing is better than Dinas bricks or Ganister bricks. The only difference between the two is the quantity of silica contained in each. A good Ganister brick has assayed out at the following proportions:—

Silica	96·4	per cent.
Alumina	1	,,
Lime	1·25	,,
Sundry oxides	1·35	,,

Ganister bricks do not, on cooling, crack so quickly as Dinas bricks, because Dinas bricks having a higher percentage of silica are practically infusible and unaffected by the great heat. They should be set in very thin ganister cement, the usual plan being to dip the brick in very thin cement, and when the work is finished, to slurry over the surface with the thin cement. Up to the present time nothing better than this method has yet been devised for firebrick work.

Ganister is a refractory material much used for 'fettling' and repairing cupola linings. It is composed principally of silica, with a small percentage of alumina as a binding material. It is less plastic than fireclay, but does not crack so readily when heated. Like fireclay, it should be free as possible of soda, potash, lime, and oxide of iron.

The following analysis is given of three samples of ganister:—

	No. 1. Welsh ganister.	No. 2. Welsh ganister.	Sheffield ganister.
	Per cent.	Per cent.	Per cent.
Silica	84·54	94·70	86·48
Alumina	7·78	4·27	4·57
Oxide of iron	4·85	0·78	3·43
Lime	0·13	Trace	Trace
Magnesia	...	Trace	...
Loss on calcination	2·68	...	5·46
	99·98	99·75	99·94

In practice No. (1) was proved to be the best of the three ; No. (2) was the least satisfactory, notwithstanding its purity and high percentage of silica; it wasted and formed most copious slag, proving that however satisfactory such a material would be in a position away from the action of basic slags and oxide of iron, ganister with silica over 94 per cent is useless at the melting zone of a cupola, a greater percentage of alumina being required.

A recent invention for the manufacture of fireproof bricks consists of an improved method of manufacturing Dinas stone or firebricks. The fresh moulded masses are to be partly hardened before they are burnt, by subjecting them to the action of steam in suitable vessels, such hardening being carried only to a degree which would be sufficient to make the bricks suitable for building purposes. The fresh moulded masses, before they are burnt, are treated by steam in suitable vessels until they are so far hardened that they can be readily transported to the kiln, and can be burnt without any danger of injuring their structure. The hardening process already practised for the manufacture of calcareous sandstones, which, in the method known as the high-pressure process, occupies from ten to twelve hours, and in the method known as the low-pressure process, occupies from forty-eight to seventy-two hours, differs from the present invention in this respect : the moulded masses are subjected to the action of steam for three to twenty-four hours, and, by the present process, no completely hardened products are obtained, but only half-hardened blocks are produced, which would be unsuitable for building purposes. Experiments have shown that the degree of hardness attained by the Dinas stones or firebricks when burnt is quite independent of the extent of the preliminary hardening by steam, such as referred to. Thus, the firebricks are found to be equally hardened after burning, where they were either partly hardened by steam, or completely hardened as now practised in the manufacture of calcareous sandstone. It will thus be seen that by the present process considerable economy is effected, as there is obtained a quantity of products ready for the succeeding burning operations, which quantity is approximately three times greater than that obtained during the time now occupied for the pre-hardening of stones in the manufacture of calcareous sandstones for building purpose. Consequently, the size and capacity of the hardening vessels may be diminished, while there is an essential saving of steam and coal. The drying and warming of the moulded mass, as compared with the present air-drying method now completely employed for the manufacture of firebricks, is effected in considerably shorter time by the present process.

Where analysis of fireclay is inconvenient or not available, a simple test may be made by means of a pot furnace such as brass-founders use. A portion of the clay is formed into a small pyramid, having sharp angles and apex. Dry the pyramid with a gentle heat. Then place it in a small crucible, fix on the lid with a little fireclay of known good quality, and subject the crucible to a good strong heat for an hour or more in the pot furnace. If only of fair quality, the pyramid will show signs of fusion. If of bad quality, instead of the pyramid, the clay will be a formless mass.

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